Nuclear Spent Fuel & Homeland Security

The Case for Robust Storage

Citizen's Awareness Network

C-10 Research & Education Foundation • Safe Sustainable Energy •

2006

Sources

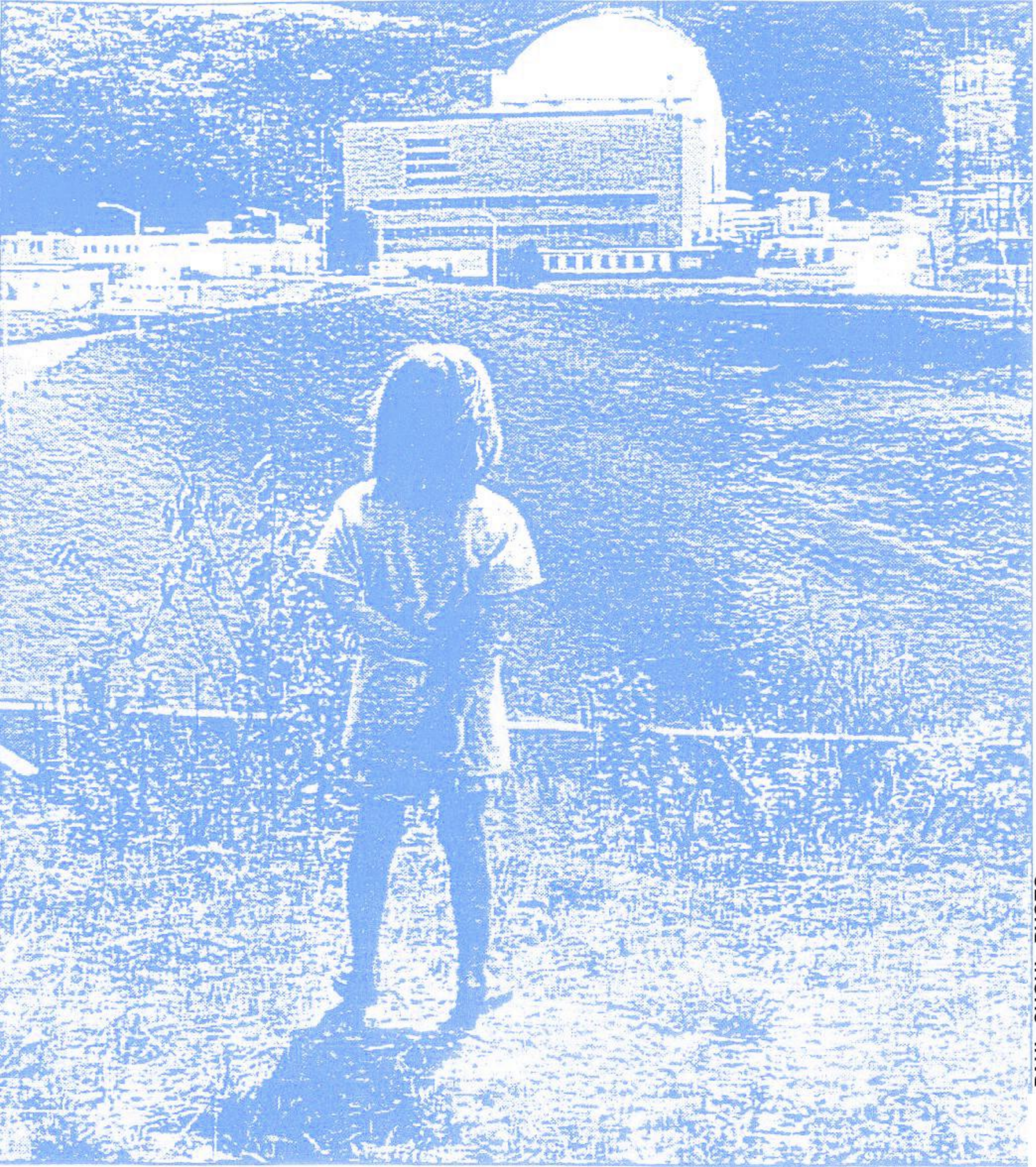
This presentation highlights the information contained in three reports.

Direct quotes from these reports were used whenever practical:

•"**Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report**"
National Academy of Science, 2005

•"**Reducing the Hazards from Stored Spent Power Reactor Fuel in the United States**",
by Robert Alvarez; Jan Beyea; Klaus Janberg; Jungmin Kang; Ed Lyman;
Allison Macfarlane; Gordon Thompson; and Frank N. von Hippel, 2003

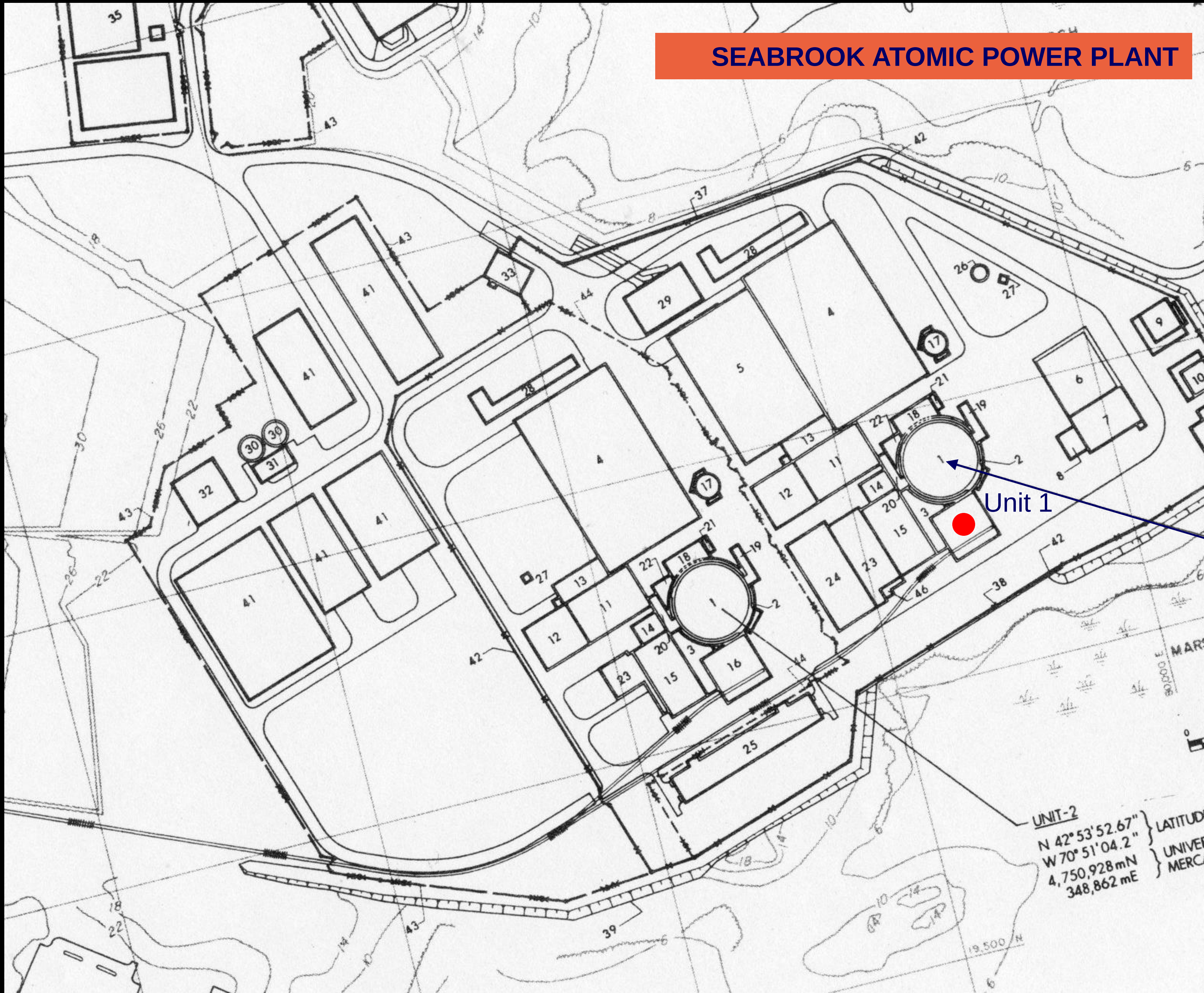
•"**Robust Storage of Spent Nuclear Fuel: A Neglected Issue of Homeland Security**"
by Gordon Thompson, Institute for Resource and Security Studies, 2003



PAUL SHOUL PHOTO

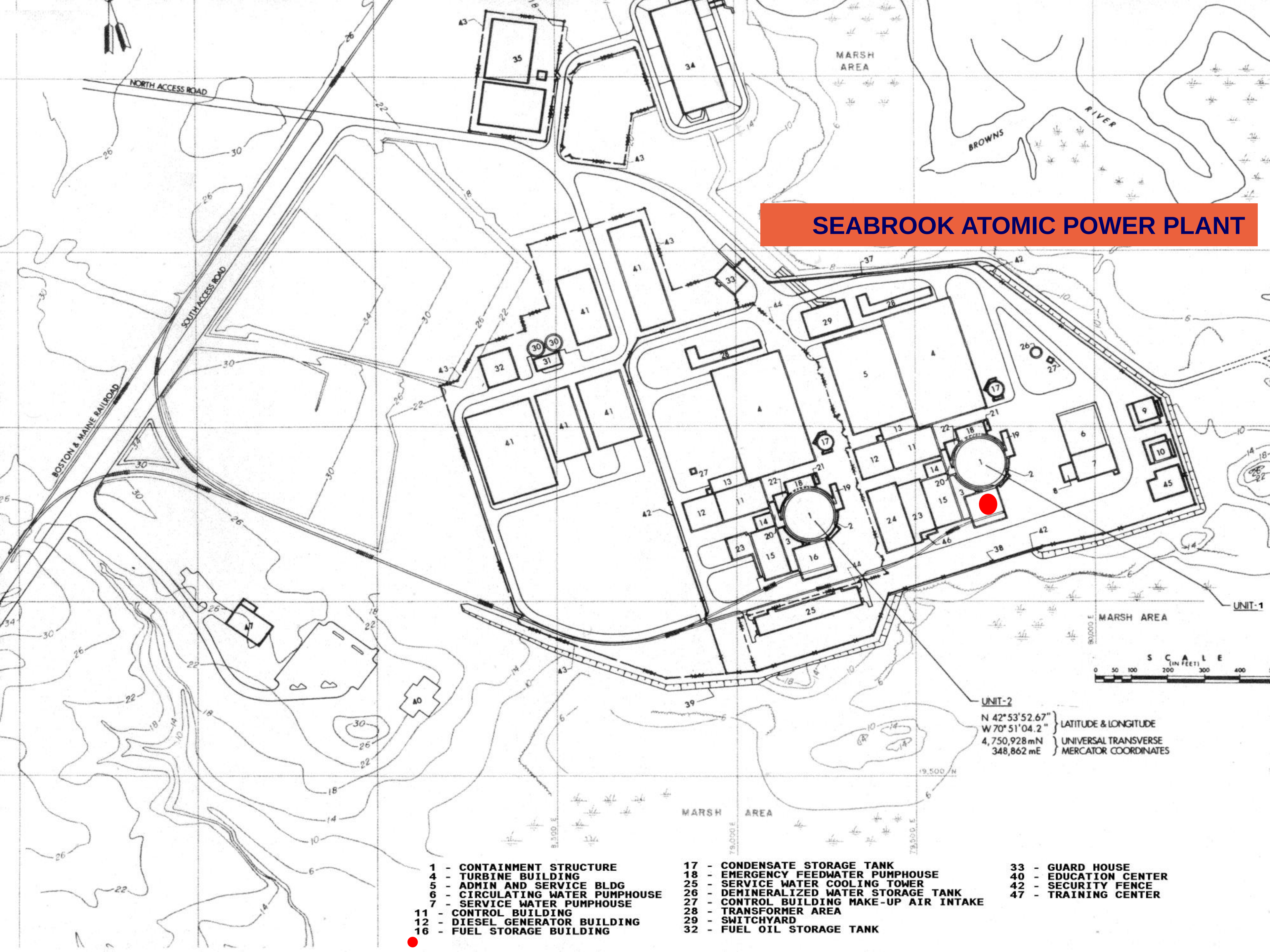
Exercise Precaution

SEABROOK ATOMIC POWER PLANT

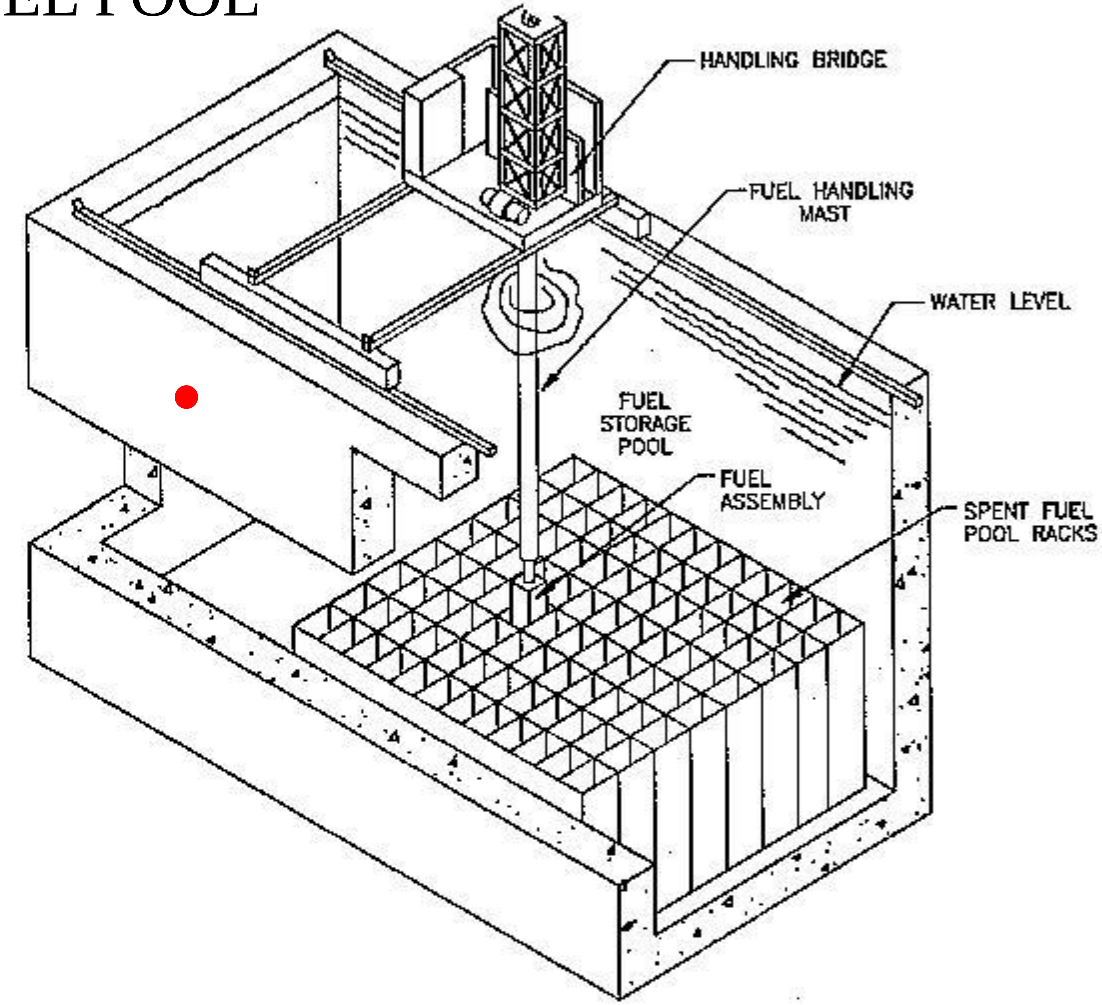


Vulnerability

SEABROOK ATOMIC POWER PLANT



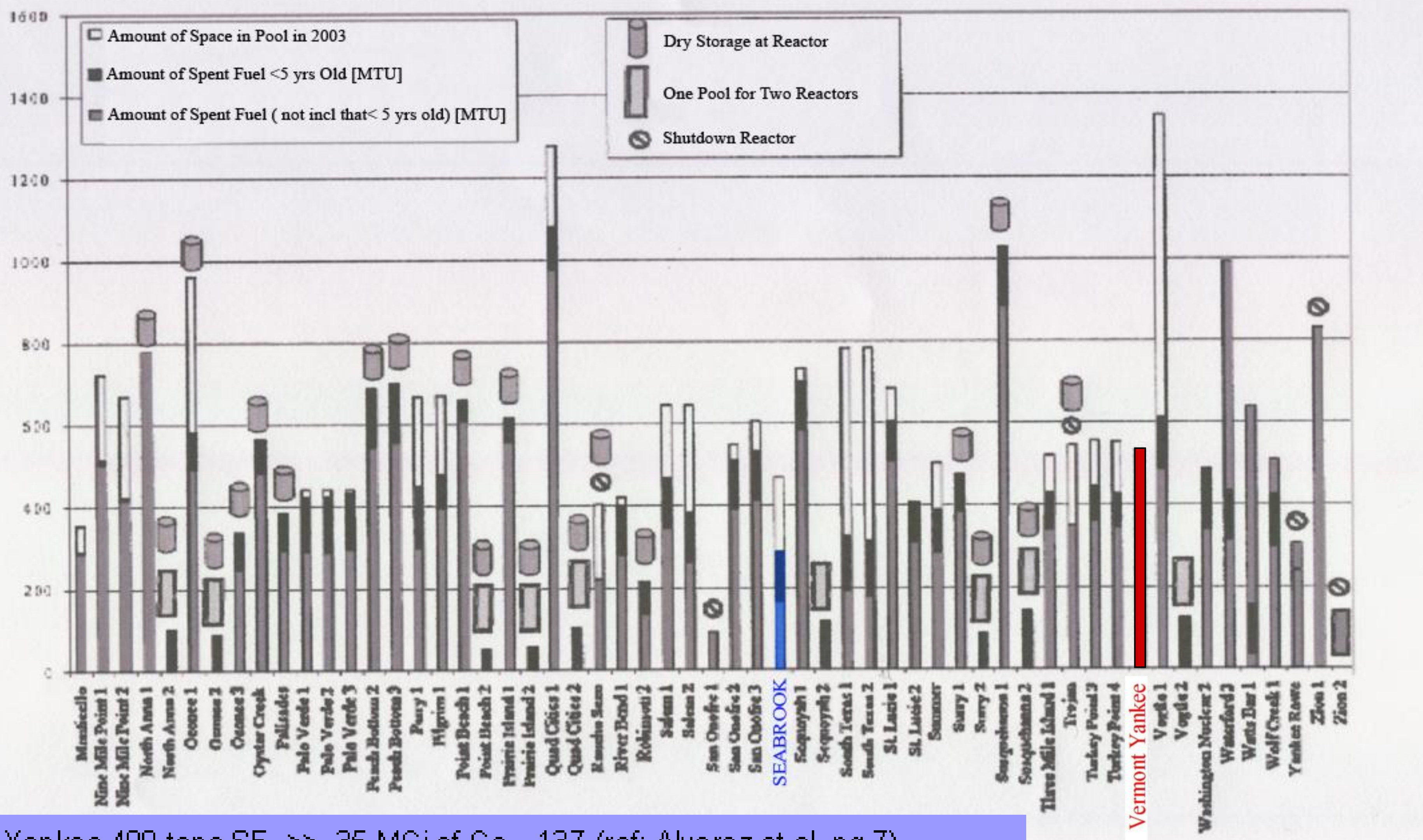
SPENT FUEL POOL



400 tons of spent fuel >> 35 million curies (MCi) of Cesium -137 (Cs-137)…

35 MCi Cs-137 = 17 times the Cs-137 released from Chernobyl

U.S. Commercial Reactor ‘Spent’ Fuel Pool Inventories



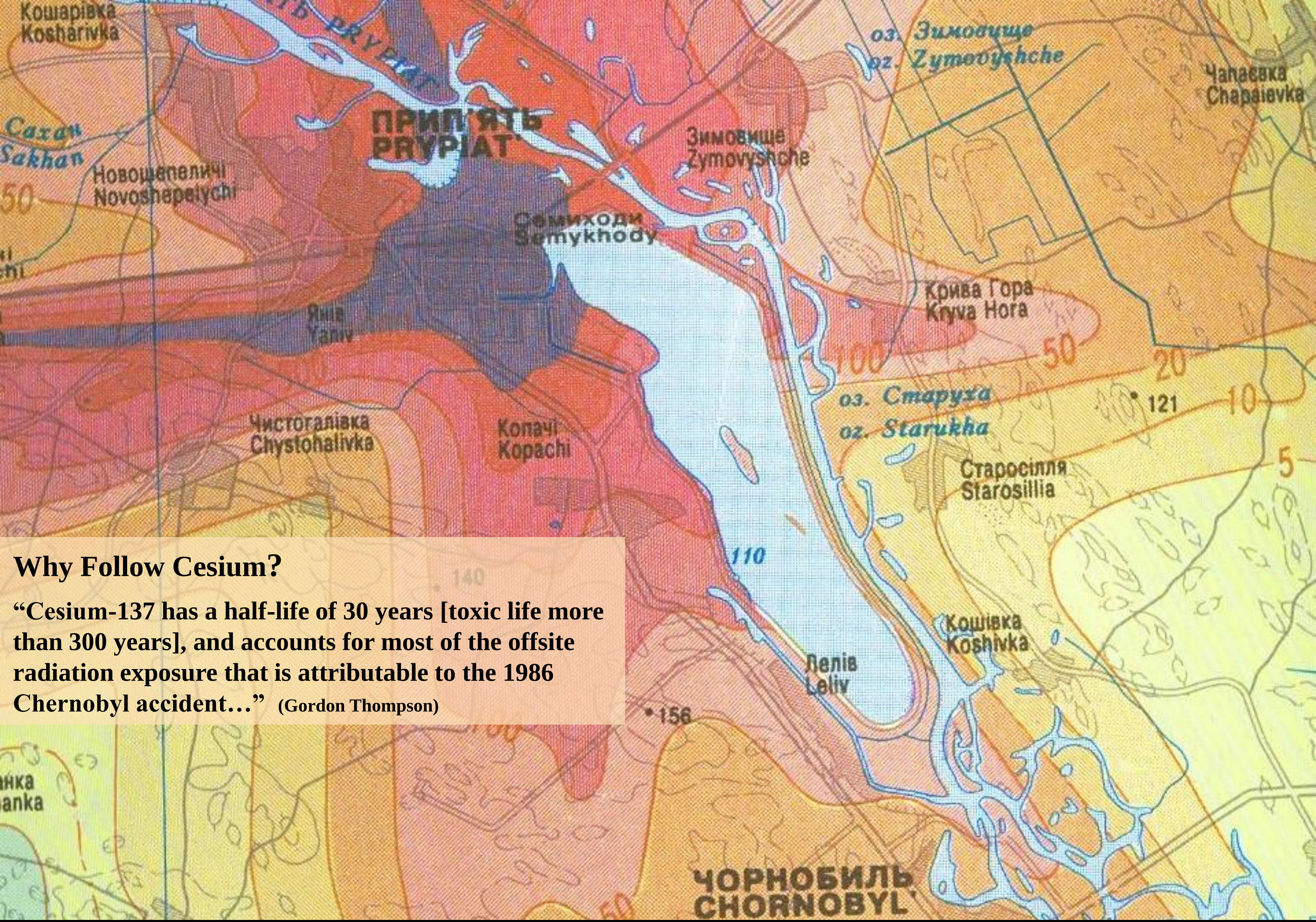
Vt. Yankee 400 tons SF >> 35 MCi of Cs – 137 (ref: Alvarez et al, pg 7)

Seabrook (300 tons): 400 t / 35 MCi = 300 / X [Seabrook]

400X = 10,500 X [Seabrook] = 26.25 MCi

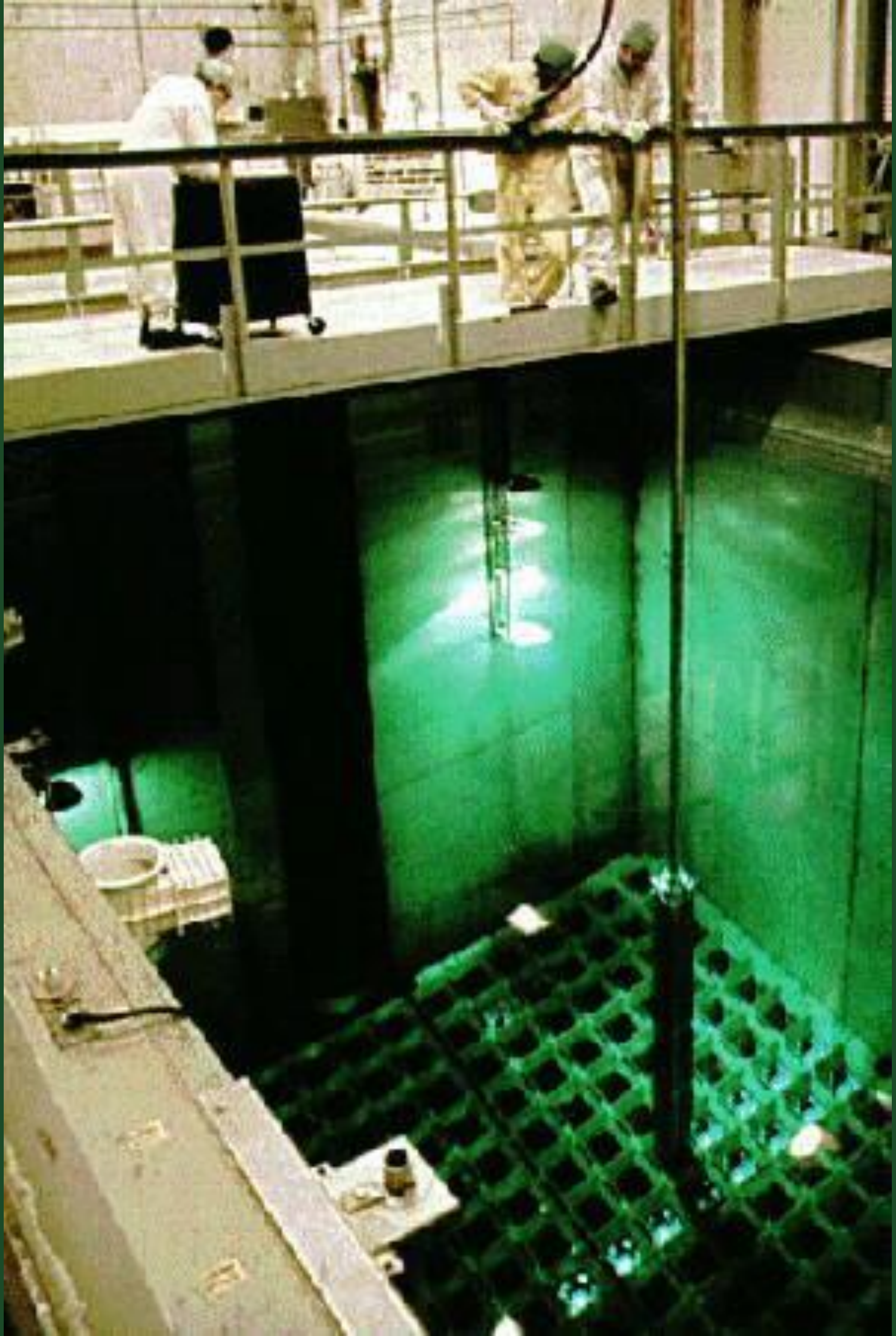
Figure 3

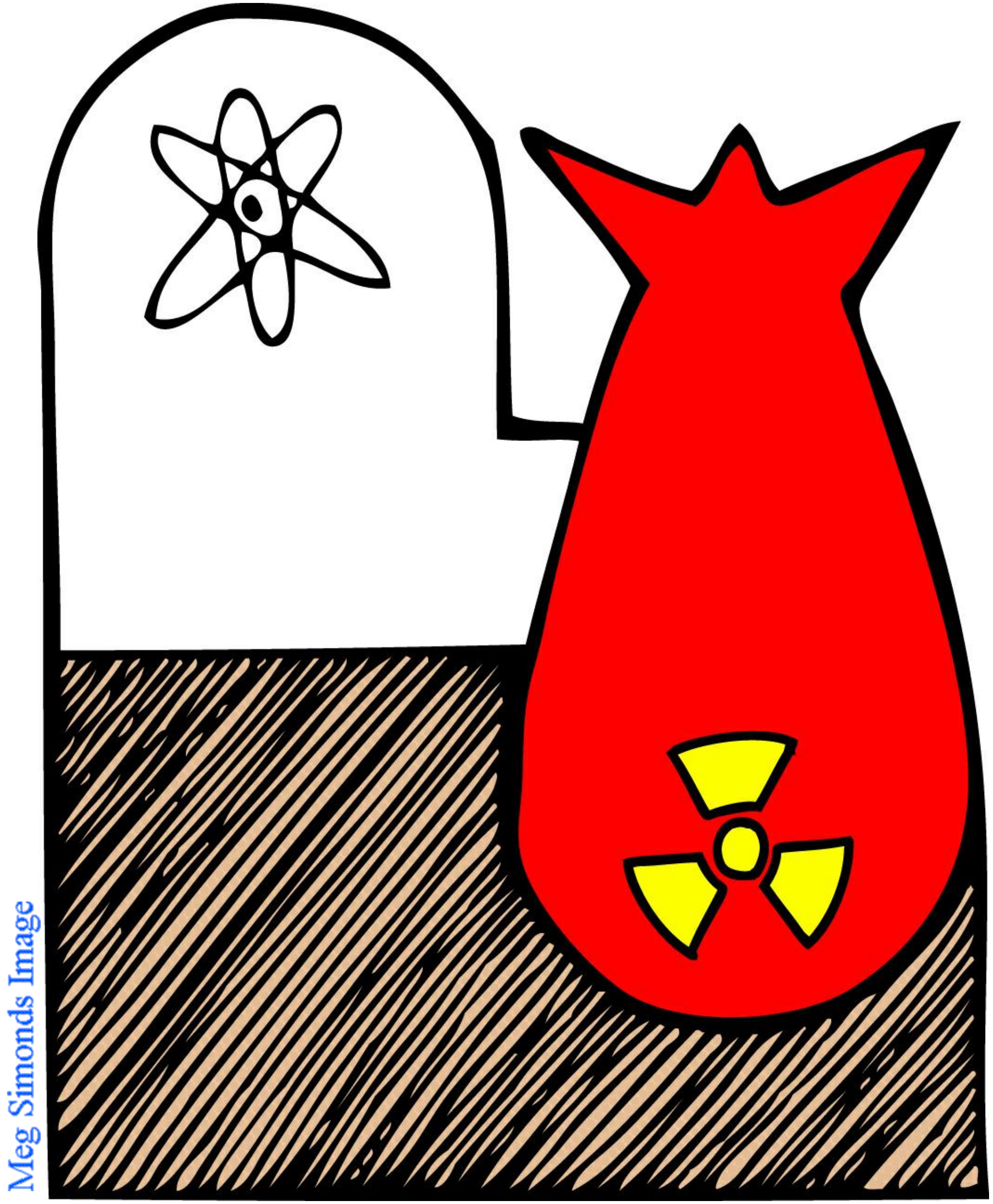
From Alvarez, et al, “Science and Global Security, 11:1-51, 2003



Why Follow Cesium?

"Cesium-137 has a half-life of 30 years [toxic life more than 300 years], and accounts for most of the offsite radiation exposure that is attributable to the 1986 Chernobyl accident…" **(Gordon Thompson)**




Meg Simonds Image

MODE OF ATTACK	CHARACTERISTICS	PRESENT DEFENSE
Commando-style attack	• Could involve heavy weapons and sophisticated tactics • Successful attack would require substantial planning and resources	Alarms, fences and lightly-armed guards, with offsite backup
Land-vehicle bomb	• Readily obtainable • Highly destructive if detonated at target	Vehicle barriers at entry points to Protected Area
Anti-tank missile	• Readily obtainable • Highly destructive at point of impact	None if missile launched from offsite
Commercial aircraft	• More difficult to obtain than pre-9/11 • Can destroy larger, softer targets	None
Explosive-laden smaller aircraft	• Readily obtainable • Can destroy smaller, harder targets	None
10-kilotonne nuclear weapon	• Difficult to obtain • Assured destruction if detonated at target	None

TABLE 1

SOME POTENTIAL MODES OF ATTACK ON CIVILIAN NUCLEAR FACILITIES

Thompson, pg 39

F-111

AIRCRAFT AS INSTRUMENTS OF ATTACK - Boeing 767

Type	Max t/o Weight	Fuel Capacity
737	56 – 63 Tons	5,000 Gallons
757	104 – 116 Tons	11,000 Gallons
767	136 – 181 Tons	16,000 Gallons

*converted from metric

type used in 9/11 attacks

Boeing 737 – 63 Tons Maximum Take-Off Weight

Photo: Allen Matheson / Photohome.com

Shearon Harris atomic reactor, North Carolina

The Union Leader NEW HAMPSHIRE SUNDAY NEWS

December 17, 2004

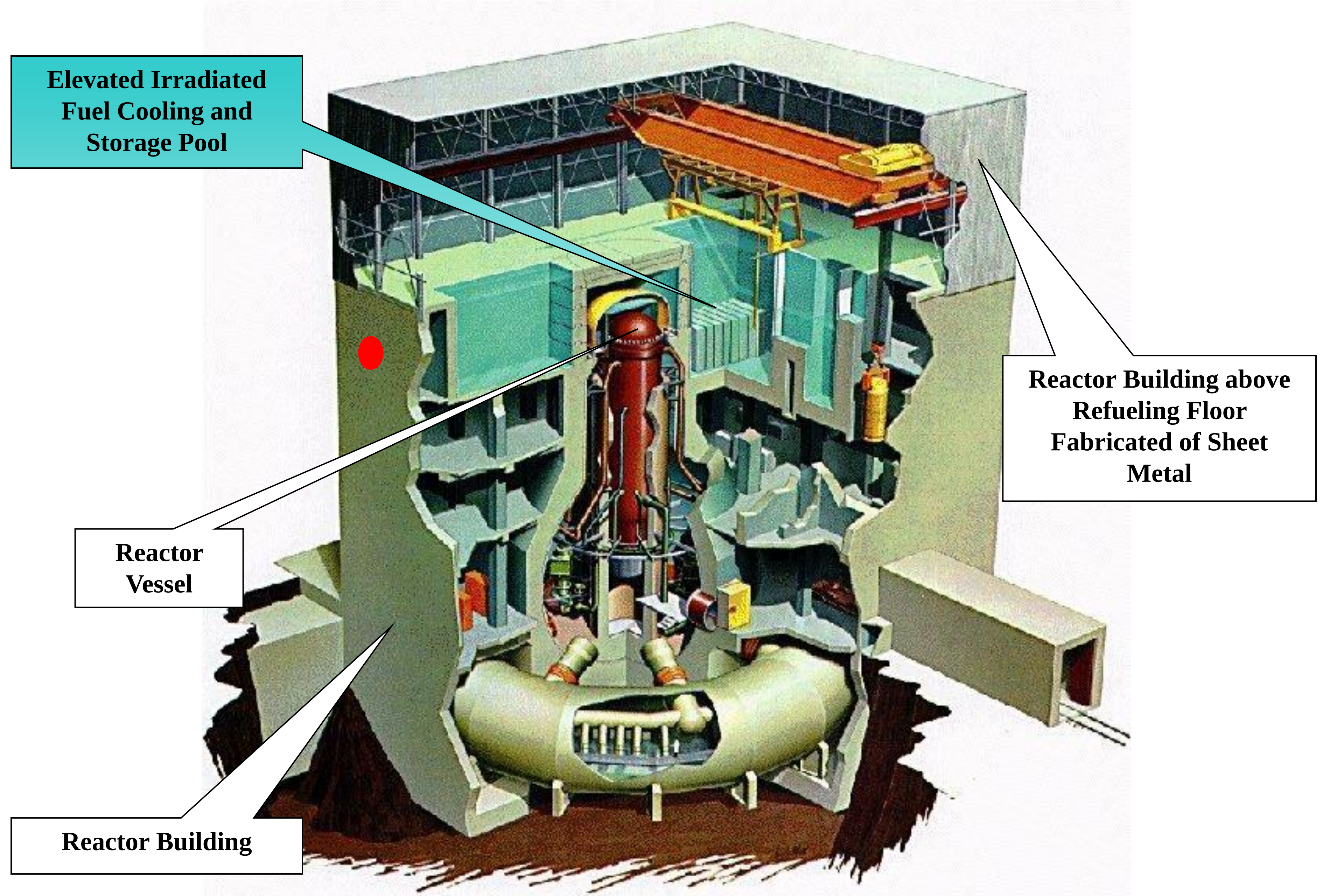
Official: Iran Targeted Seabrook for Attack

By Benjamin Kepple, Union Leader Staff

A Pennsylvania congressman said he has been told of an Iranian plan to hijack Canadian airliners and crash them into the nuclear-fueled Seabrook Station. (DAVID LANE/UNION LEADER FILE PHOTO)

THREE MILE ISLAND Harrisburg, PA

Vermont Yankee, looking east to Cheshire County, New Hampshire



General Electric Mk 1 "Boiling Water" Reactor

SEABROOK ATOMIC REACTOR

Attack Consequence

Spent Fuel Assemblies

in high-density racking

Spent Fuel Pool: Loss of Coolant Consequence

"At the lower radiation level, lethal doses would be incurred within an hour. Given such dose rates, the NRC staff assumed that further *ad hoc* interventions would not be possible."

(Alvarez, et al, pg 12 & 14)

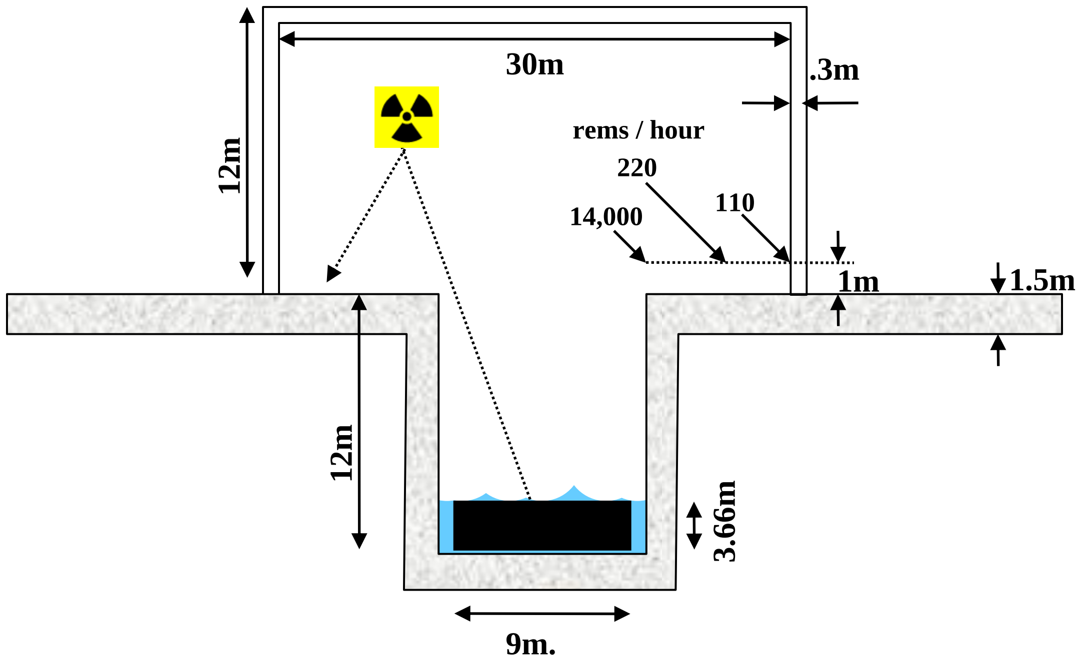
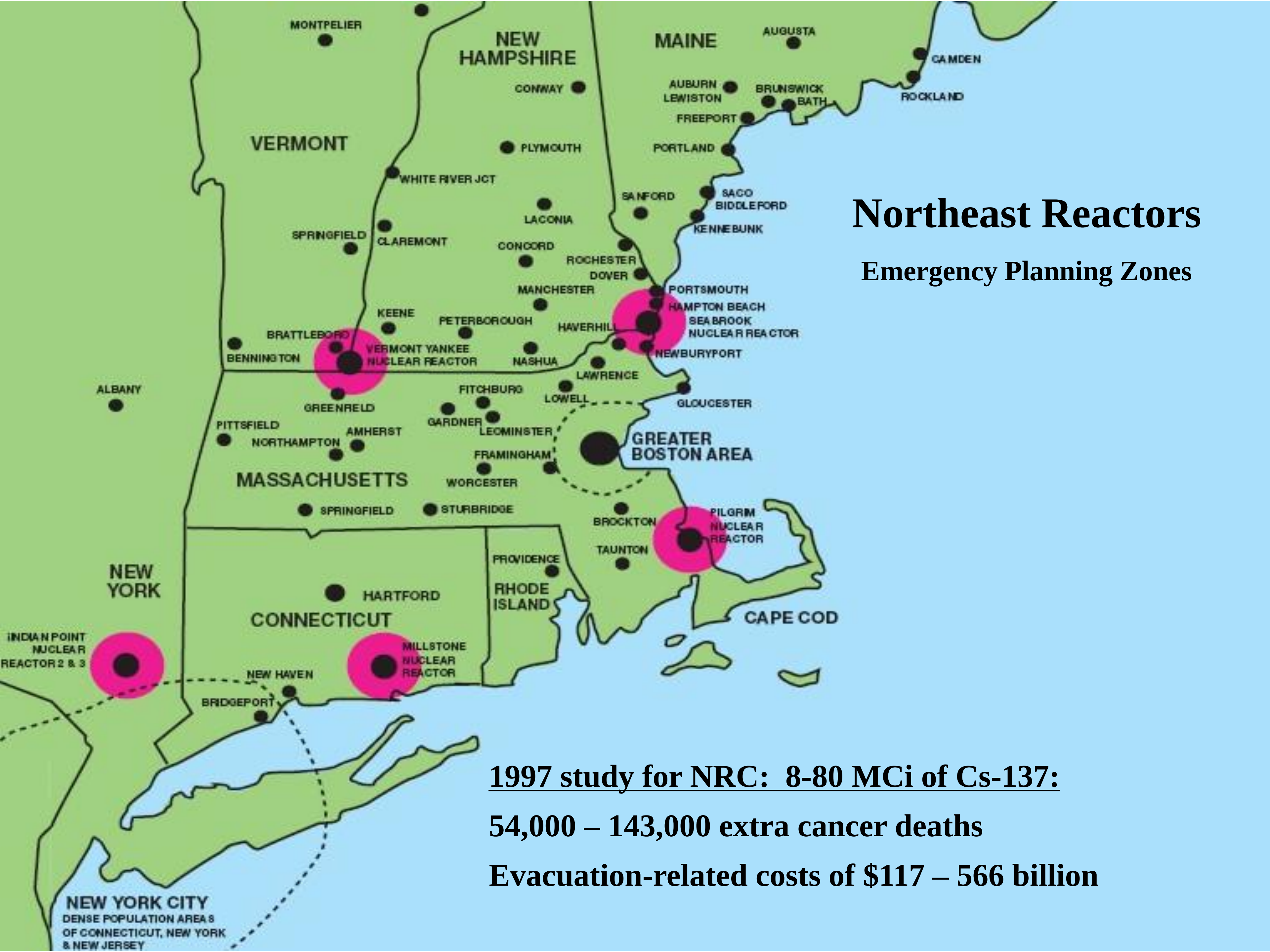


Figure 6. Calculated radiation levels from a drained spent-fuel pool one meter above the level of the floor of a simplified cylindrically-symmetric spent-fuel-pool building. Even out of direct sight of the spent fuel, the radiation dose rates from gamma rays scattered by the air, roof and walls are over a hundred rems/hr. (Alvarez et al, pg 14)

Northeast Reactors

Emergency Planning Zones



<u>1997 study for NRC: 8-80 MCi of Cs-137:</u>

54,000 – 143,000 extra cancer deaths

Evacuation-related costs of \$117 – 566 billion

Cesium-137 Plume Models

[Projected wind-blown radiation]

Alvarez et al. Reducing U.S. Stored Spent Reactor Fuel Hazards 11

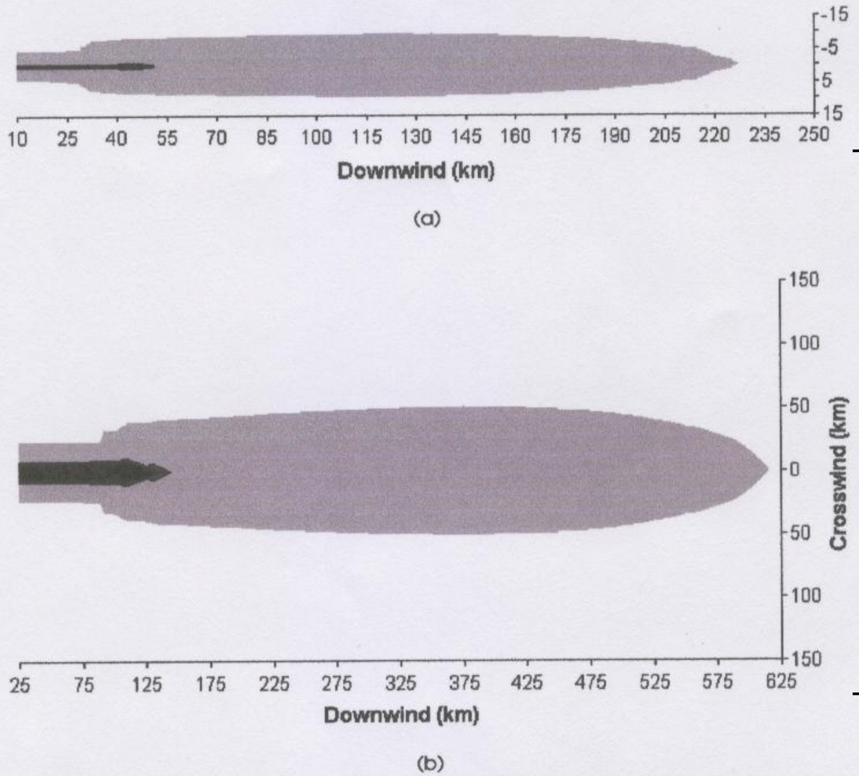


Figure 4: Typical areas contaminated above 100 (shaded) and 1000 (black) Ci/km^2 for release of (a) 3.5 MCi and (b) 35 MCi of ^{137}Cs. The added chance of cancer death for a person living within the shaded area for 10 years is estimated very roughly as between 1 and 10 percent. For someone living within the black area, the added risk would be greater than 10 percent (i.e. the "normal" 20% lifetime cancer death risk would be increased to over 30 percent.) (*Source:* authors).

3.5 MCi release:

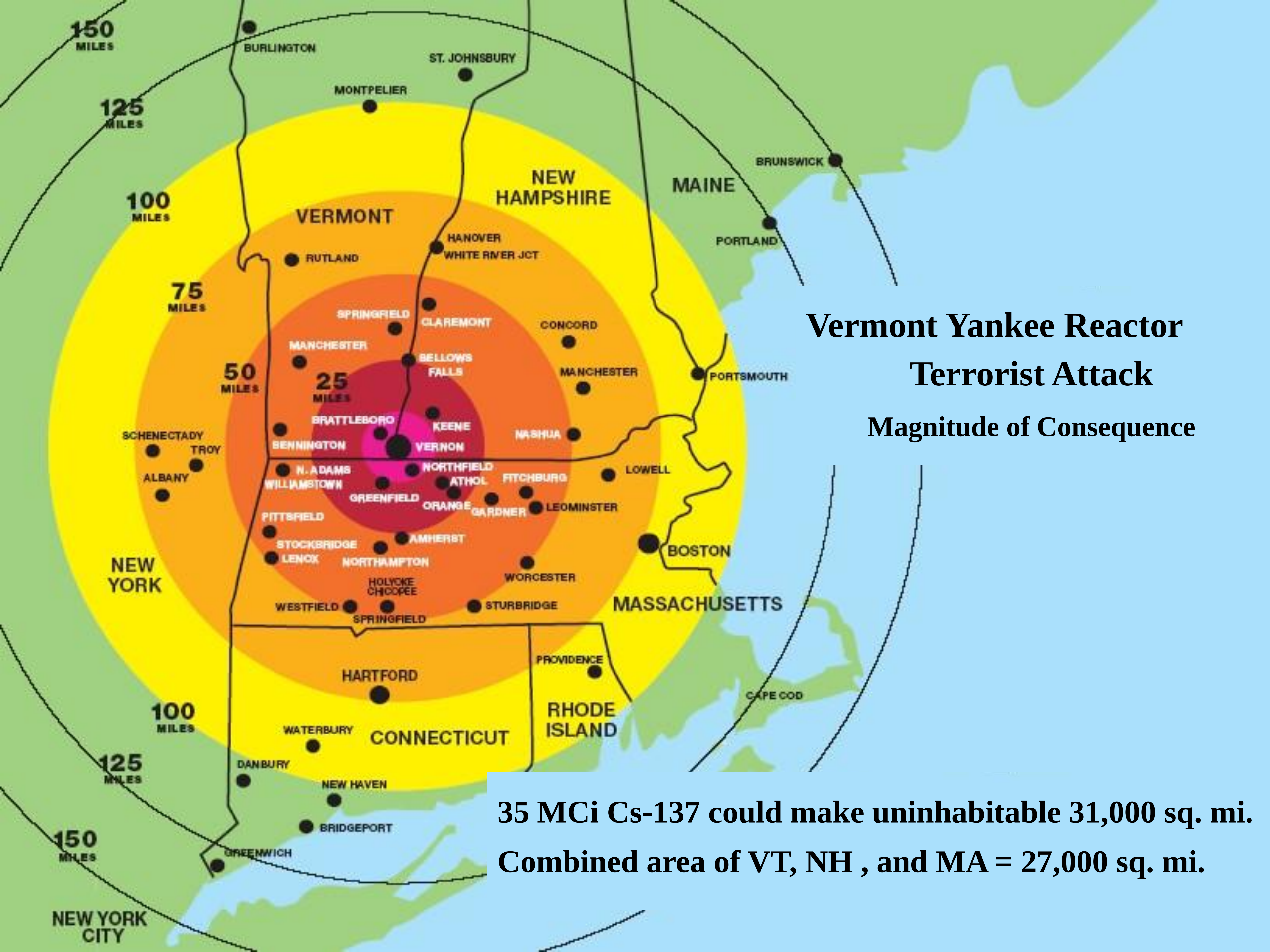
→ **142 Miles**

35 MCi release:

→ **388 Miles**

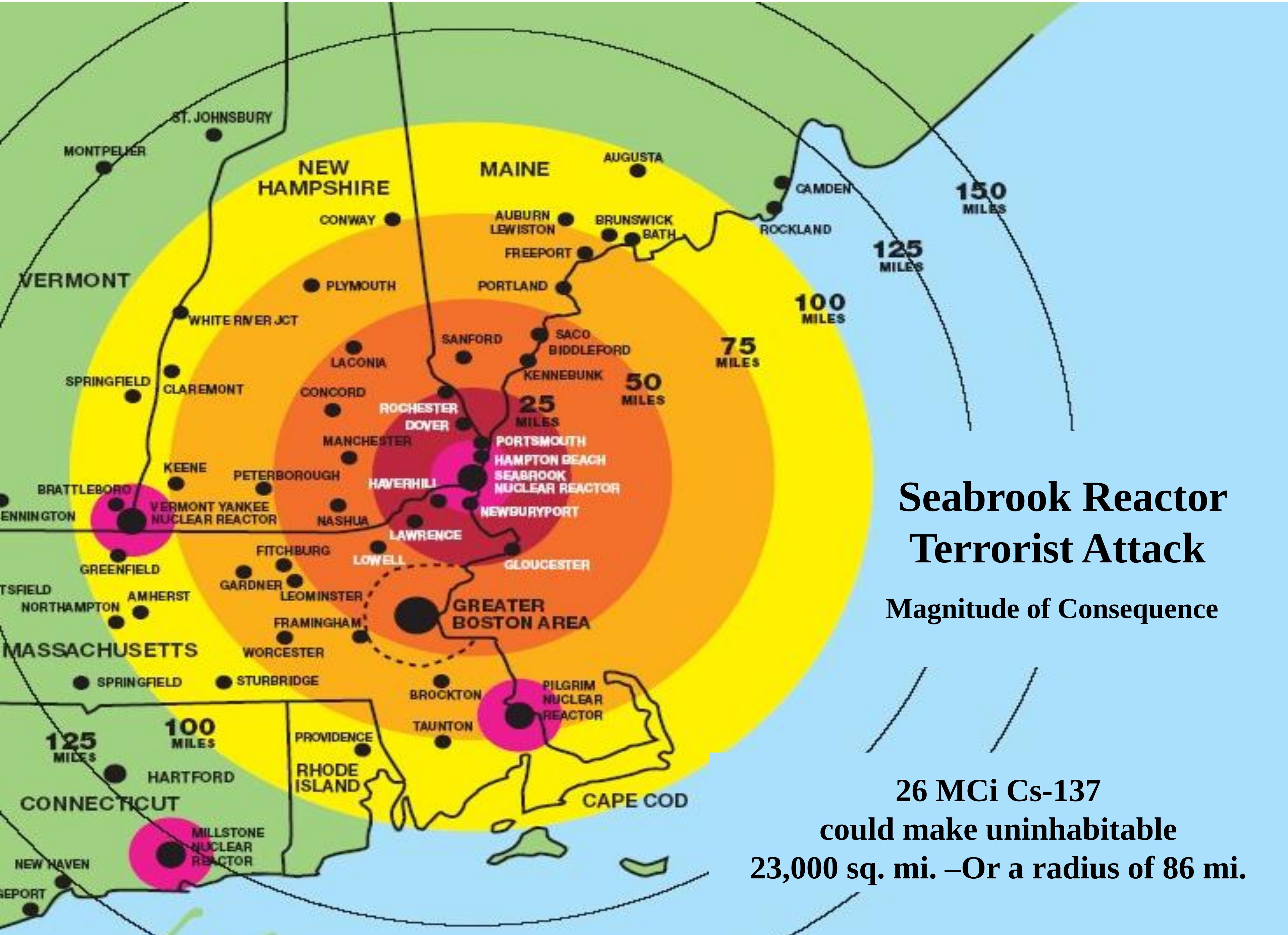
Vermont Yankee Reactor Terrorist Attack

Magnitude of Consequence



35 MCi Cs-137 could make uninhabitable 31,000 sq. mi.

Combined area of VT, NH , and MA = 27,000 sq. mi.

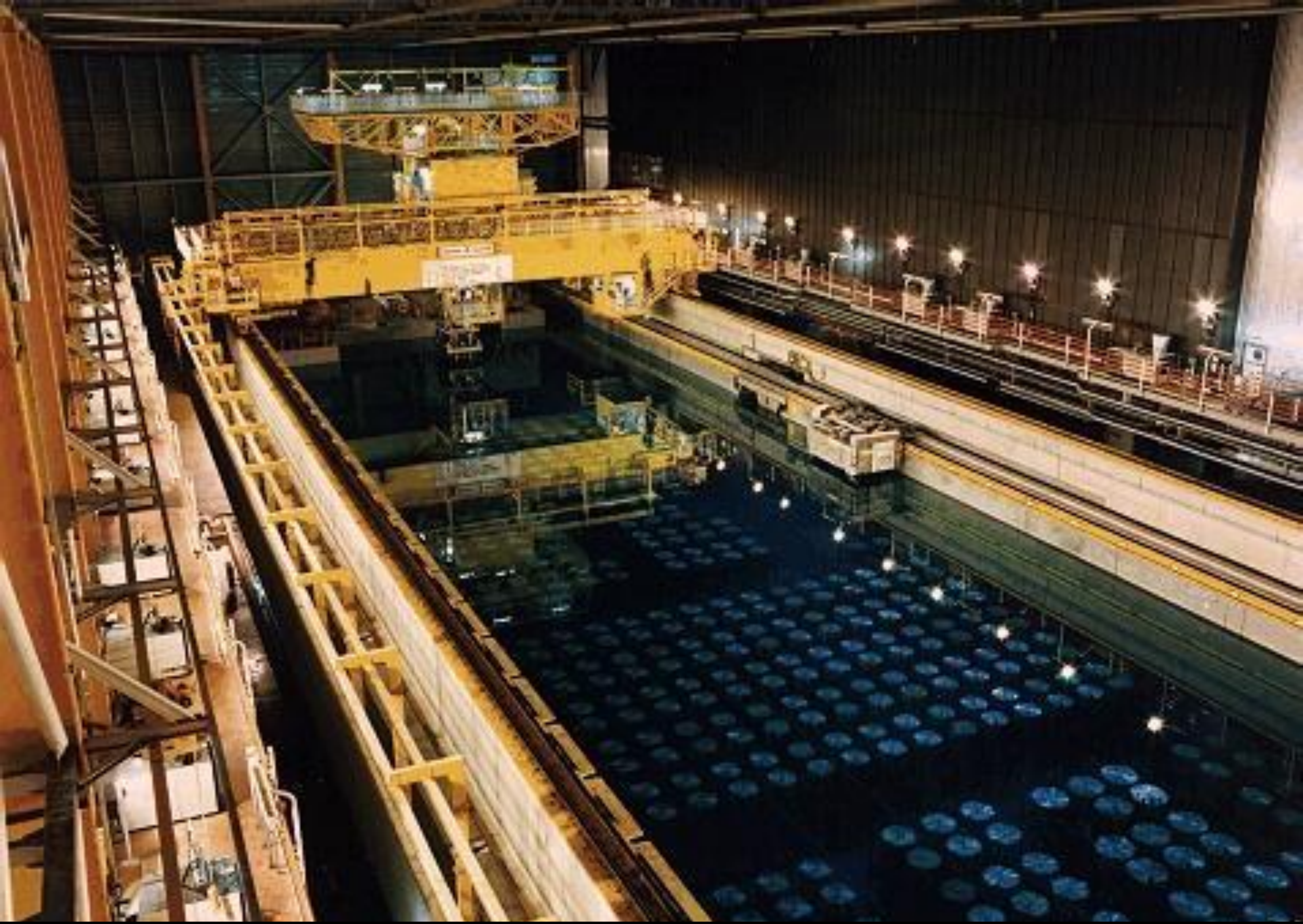


Seabrook Reactor Terrorist Attack

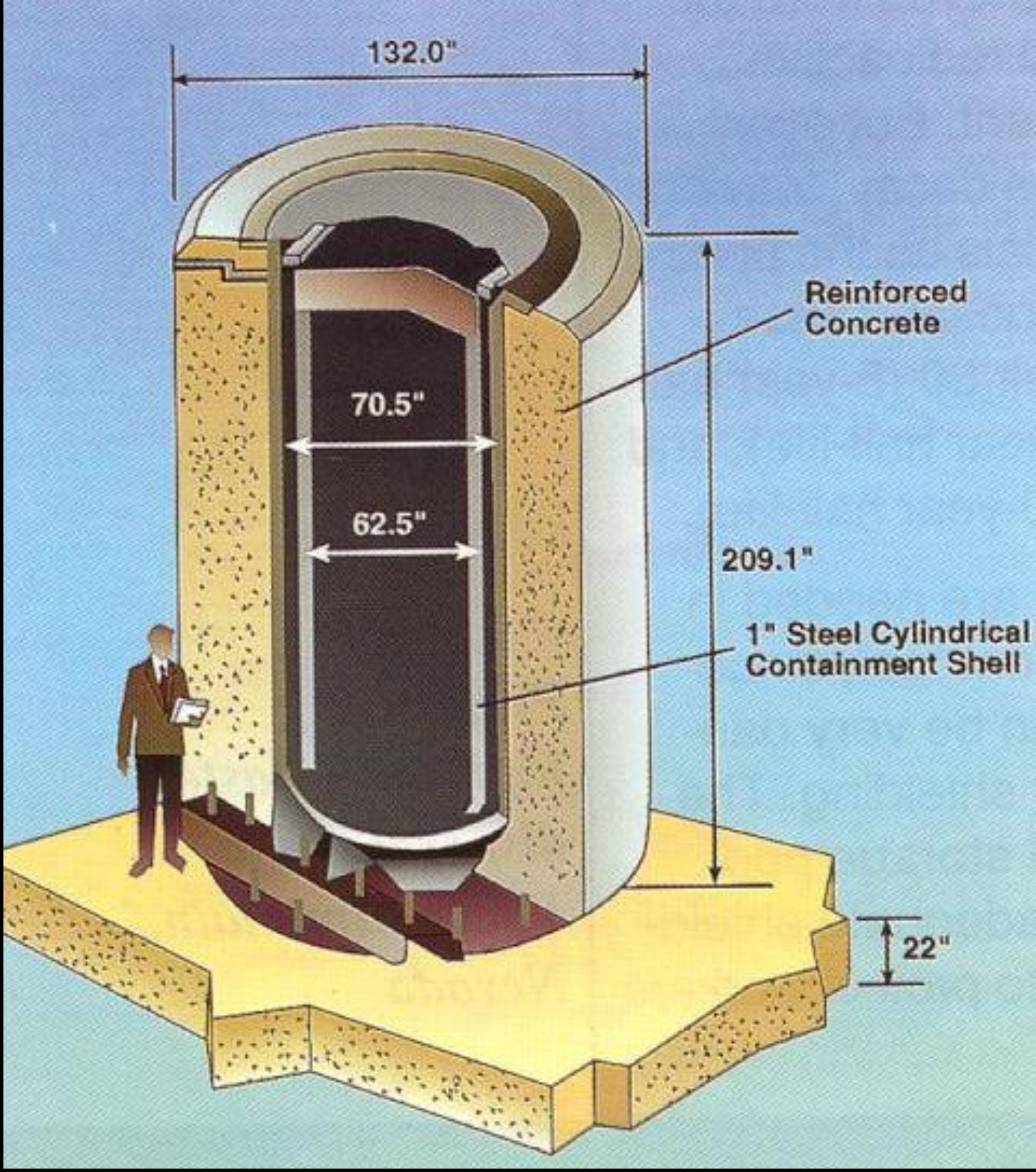
Magnitude of Consequence

26 MCi Cs-137
could make uninhabitable
23,000 sq. mi. –Or a radius of 86 mi.

“Robust” Protection for Spent Fuel



Thick-Walled Single Unit Cask



Dry Cask Storage Advantages

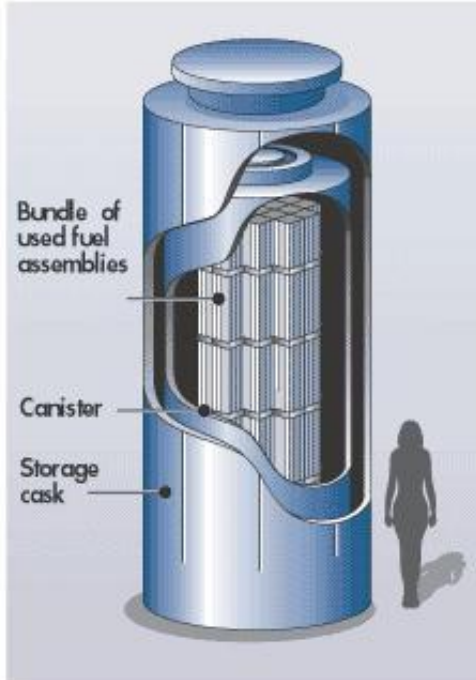
* passive air circulation

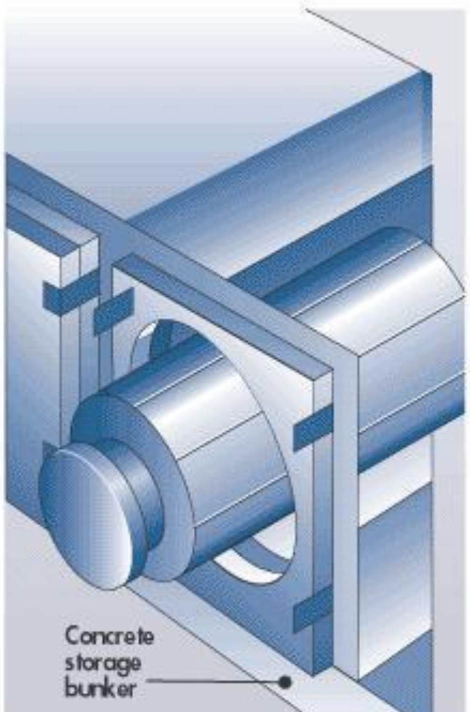
*divides the inventory among robust containers.

Dry Storage of Spent Fuel

At some nuclear reactors across the country, spent fuel is kept on site, above ground, in systems basically similar to the ones shown here.

Once the spent fuel has cooled, it is loaded into special canisters, each of which is designed to hold about 24 (Pressurized-Water Reactor) or 68 (Boiling-Water Reactor) assemblies. Water and air are removed. The canister is filled with inert gas, welded shut, and rigorously tested for leaks. It may then be placed in a "cask" for storage or transportation.





The canisters can also be stored in above-ground concrete bunkers, each of which is about the size of a one-car garage. Eventually they may be transported elsewhere for storage.

Canister / Over-pack storage system

$3.5 – 7 Billion Nation-wide

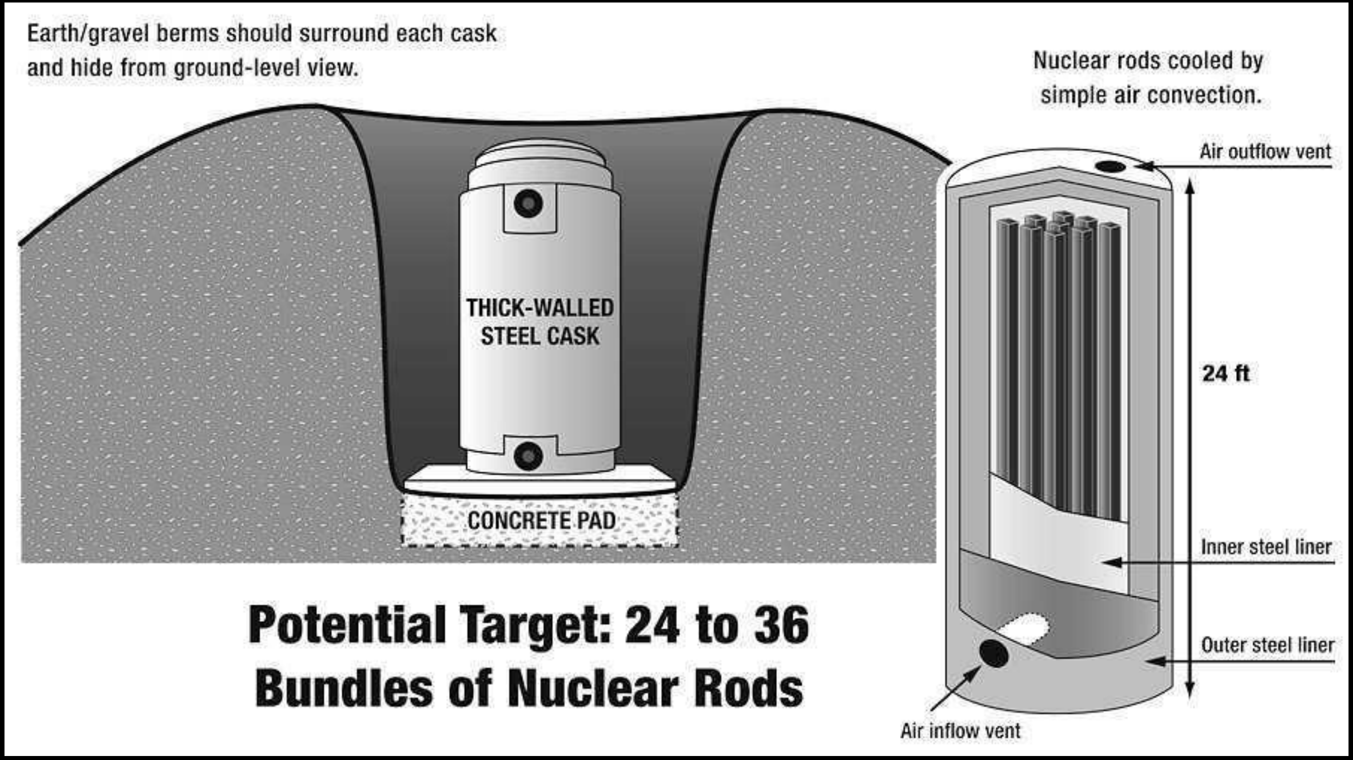
Compare to $6 Billion per month for Iraq War

Sitting Ducks

Passively Safe? **Yes** Hardened? **No** Dispersed? **No**

What is Robust Storage?

Spent Fuel Storage made resistant to attack in three ways:
passively safe; "hardened", dispersed…



Hardened On-Site Storage
(HOSS)

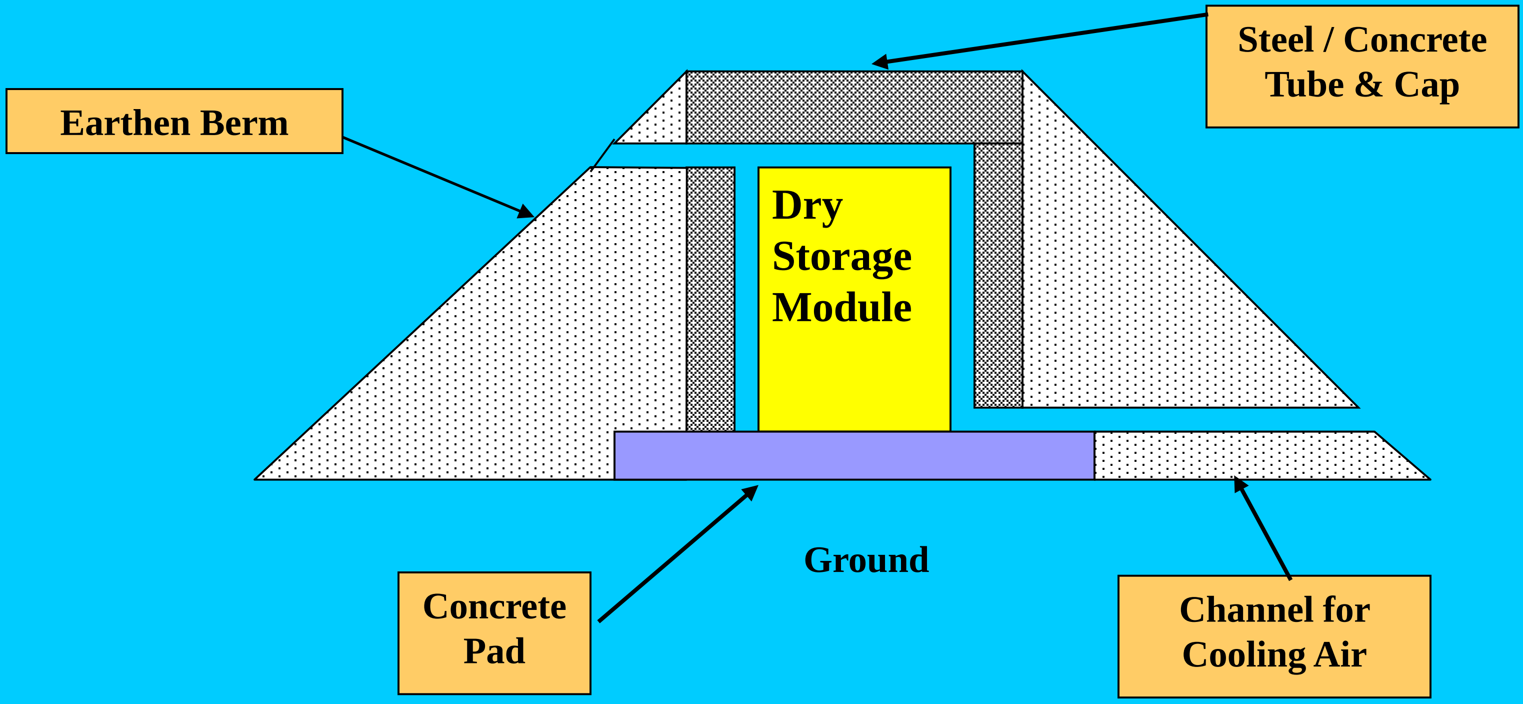
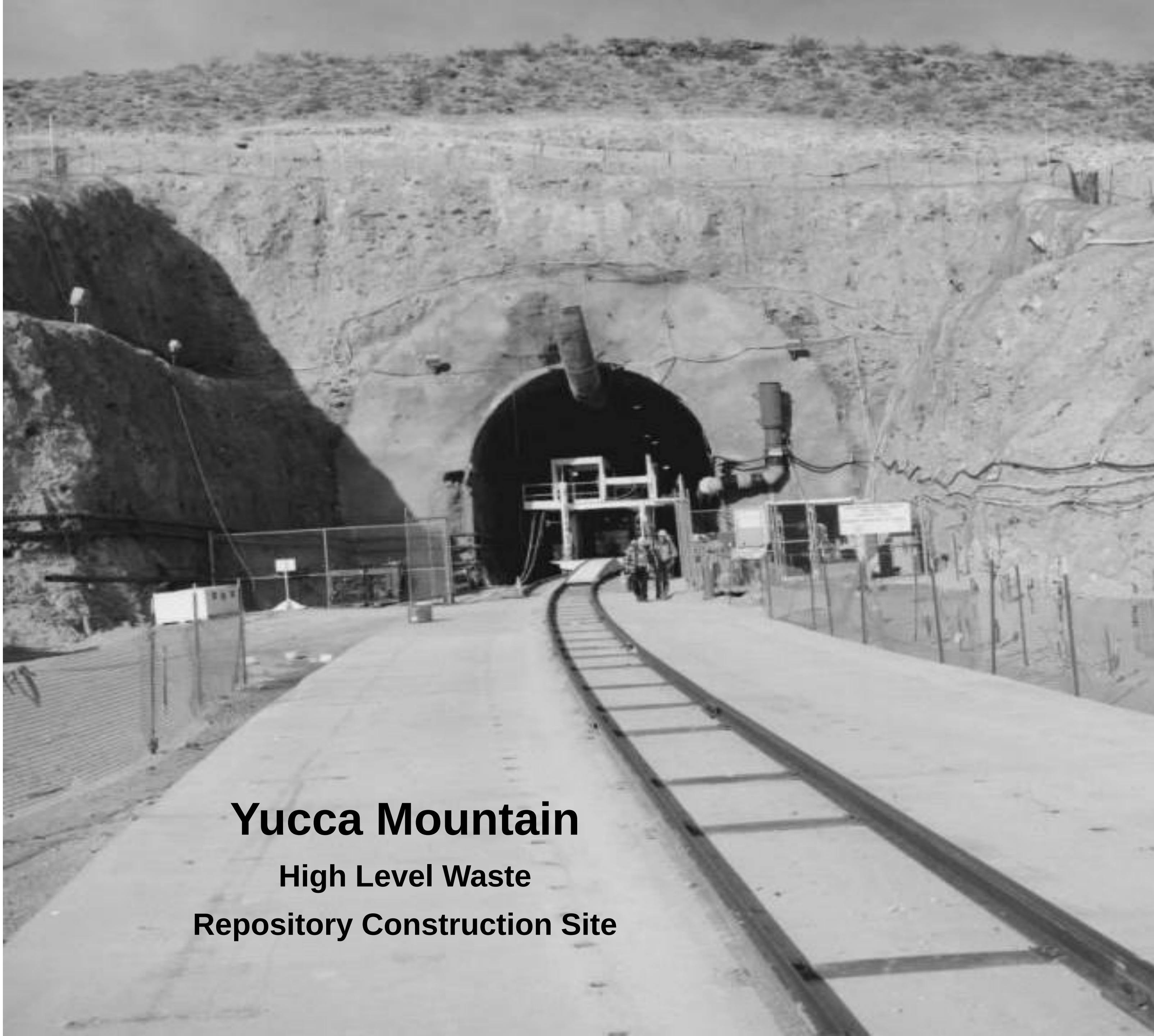


FIGURE 2

SCHEMATIC VIEW OF PROPOSED DESIGN FOR HARDENED, DRY STORAGE


Yucca Mountain
High Level Waste
Repository Construction Site

References

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"Robust Storage of Spent Nuclear Fuel: A Neglected Issue of Homeland Security" by Gordon Thompson, Institute for Resource and Security Studies, 2003

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Christopher Nord

Compiler, Narrator, Producer

Citizen's Awareness Network

We envision a future of safety, prosperity, and health for all. People generate their own electricity in their own homes and communities. Local energy production has created local jobs. Renewable energy is integrated into all of our buildings- our homes, businesses, schools, and public buildings. It is easy for everyone to access sustainable and affordable energy sources. Clean, efficient energy use is standard practice. Family farms and locally owned businesses are the backbone of our communities, and we have what we need to provide for our future.*

C-10 envisions a clean, safe and sustainable non-nuclear energy future.

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Text and Bibliography

#3 The 2005 National Academies BEIR VII Report (Biological Effects of Ionizing Radiation) underscores the need for unprecedented protection from radiation exposure – since it is now accepted there is no safe threshold, and children are most vulnerable to its effects. For the sake of our children, we must exercise precaution in our manipulations of the larger world.

#4 Let's look at three related issues. First, atomic reactors are vulnerable and extremely dangerous terrorist targets – because of their spent fuel pools.

#5 Second, a successful attack against Seabrook or Vermont Yankee's spent fuel pool could cause catastrophic health and economic consequences for a large area of the Northeast.

#6   And third, removing older "spent fuel" to hardened, bermed, dry cask storage is a relatively inexpensive means to greatly reduce the risk of catastrophic consequence from an attack on US commercial reactors.

#7 According to the National Academies of Science, "Spent fuel storage facilities cannot be dismissed as targets…because of the attractiveness of spent fuel as a terrorist target…" **(NAS Pg 4, Finding 2A)**

#8 ("**Vulnerability**")

#9 "…The Committee judges that attacks by knowledgeable terrorists with access to appropriate technical means are possible. The committee finds that, under some conditions, a terrorist attack that partially or completely drained a spent fuel pool, could..."

#10 "...lead to a propagating zirconium cladding fire and the release of large quantities of radioactive materials to the environment."   **(The National Academies of Science, Findings 2A, and 3B)**

#11 For a typical 1000 Megawatt US Pressurized Water Reactor (PWR), the spent fuel pool (SFP) inventory – 400 tons of spent fuel – contains approximately 35 million curies (MCi) of cesium -137…

#12 This is more than 17 times the Cs-137 released from the Chernobyl accident, where the "radiation control zone" today comprises an area one half the size of New Jersey. **(ref: Alvarez et al, Pg 7)**

#13 A conservative estimate of the Seabrook Spent Fuel Pool inventory of Cesium-137, based on 2003 spent fuel data, is 26 million curies.

#14 From among the dozens of dangerous fission by-products produced in an atomic reactor, why do we follow Cesium? "Cesium-137 has a half-life of 30 years [toxic life more than 300 years], and accounts for most of the offsite radiation exposure that is attributable to the 1986 Chernobyl accident… Cesium is a volatile element that would be liberally released during nuclear-facility accidents or attacks… an NRC study has concluded that… the fraction of the pool's inventory of Cesium isotopes that would reach the atmosphere – is 100%." (**Thompson, pg 49**)

#15 "A fire in a high-density pool, once initiated, would eventually involve all of the fuel in the pool… pool buildings are not designed as containment structures."

#16 "Thus, nuclear power plants and their spent fuel can be regarded as pre-deployed radiological weapons that await activation by an enemy. The US government and the Nuclear Regulatory Commission [NRC] seem unaware of this fact…" (**Ibid, pg 3: "Abstract"**)

#17 While various modes of attack are foreseen, none with the greatest likelihood of causing serious damage can presently be defended against, at reactor sites.

#18 Seabrook was one of only four reactors in the US designed to withstand the impact of an aircraft – specifically a plane weighing six tons. The Mach 2 fighter shown here, stationed at Pease Air Force Base during Seabrook's construction, weighs 22 tons empty. (**Ibid, pg 10**)

#19 Fully-fueled commercial aircraft must be considered. Complete combustion of 13,000 gallons of jet fuel – less than a full tank for Boeing 767 – will yield the energy equivalent to 450 Tons of TNT. (**Ibid, pg 36**)

#20 5,000 gallons – a full tank for a 737 (used in 9/11/01 attacks) -- yields energy equivalent to 173 Tons of TNT. (**Ibid**)

Conversion: 100,000 liters (l) fuel >> 900 tonnes TNT
50,000 l x 1.05 [quart conver.] ÷ 4 = 13,000 gallons >> 450 tons TNT
13,000 / 450 = 5000 / X 13,000 X = 2,250,000 X = 173.07 tons TNT

In September, 1982 litigation before the Atomic Safety and Licensing Board [ASLB]…"

#21 "...Wells Eddleman contended that "The plant's safety analysis was deficient because it did not consider the consequences of terrorists commandeering a very large airplane…and diving it into the containment."

…In rejecting this contention, the ASLB stated: "… the principle thrust of section 50.13 is that military style attacks with heavier weapons are not a part of the design basis threat for commercial reactors….Thus Applicants are not required to design against such things as artillery bombardments, missiles with nuclear warheads, or kamikaze dives by large airplanes, despite the fact that such attacks would damage and may well destroy a commercial reactor." (**Ibid, pg 18 – emphasis added**)

22 The evidence indicates at least two recent plots to target US atomic reactors: Seabrook in 2004, and one earlier. "…US authorities have obtained information suggesting that the hijackers of United Airlines flight 93, which crashed in Pennsylvania on 11 September 2001…"

23 "...were planning to hit a nuclear plant This may be true or false, or the truth may never be known. Whatever the truth is, it would be foolish to regard nuclear plants as immune from attack." (**Ibid, pg 26**) * ref: **Rufford, Leppard and Eddy, 'Nuclear Mystery: Crashed plane's target may have been reactor', The Sunday Times, London, 20 October 2001)**

24 Vermont Yankee's spent fuel pool (SFP) lies just under the white top of the reactor building. Within the SFP, 35 million curies of cesium-137 (only one of many fission "by-products") lay submerged in high-density racks. Note the lack of 'containment' dome. Across the Connecticut River, the hills of Cheshire County, New Hampshire. (**Thompson, pg 51**)

25 Vermont Yankee, Pilgrim, Fitzpatrick (NY), Nine Mile Point (NY), and Millstone (CT) all have one General Electric Boiling Water reactor, with the Spent Fuel Pool above the reactor.

26 "The Seabrook PRA (Probabilistic Risk Assessment) finds that any direct impact on the containment weighing more than 37 tonnes, will lead to penetration of the containment and a breach in the reactor coolant circuit…. a similar impact on the control building or auxiliary building will inevitably lead to a core melt." (**Thompson, pg 41**)

27 ("**Attack Consequence**") "In the absence of any cooling, a freshly discharged core would heat up adiabatically [without any additional heat] within an hour, to about 600˚C [1100˚ F],

28 …where the zircaloy cladding would be expected to rupture under the internal pressure from helium and fission product gasses; and then, to about 900˚C [1650˚F]…"

#29 "...the cladding would begin to burn in the air." (**Alvarez, et al pg 16; *Ref: Brookhaven National Laboratory 1997**)
"…An attack on a reactor could lead to a rapid-onset core melt with an open containment, accompanied by a raging fire.

#30 ….That event would create high radiation fields across the site, potentially precluding any access to the site by personnel… Once a fire has begun, it could be impossible to extinguish. Spraying water on the fire could feed an exothermic [heat releasing] zirconium steam reaction that would generate flammable hydrogen. High radiation fields could preclude the approach of fire-fighters" (**Thompson, pg 45**)

#31 A 1997 study done for the NRC estimated the median consequences of a spent fuel fire at a pressurized water reactor (PWR) that released 8-80 MCi of 137Cs. These included: 54,000 – 143,000 extra cancer death, 2000-7000 km ^{2} [772 – 2702 sq mi] of agricultural land condemned and economic costs due to evacuation of $117 – 566 billion. (**Alvarez et al, Pg 10**)

#32 "One measure of the scope of radiation exposure attributable… to deposition of Cesium-137 is the area of land that would become uninhabitable… the threshold of uninhabitablity is an external, whole-body dose of 10 rem over 30 years… [this] corresponds to an average dose rate of .33 rem/year… the National Research Council… has estimated that a continuous lifetime exposure of .1 rem/year would increase the rate of fatal cancer… by 2.5% (males) and 3.4% (females)… Thus, an average lifetime exposure of .33 rem/year would increase the incidence of fatal cancers of 8% (males) and 11% (females). The increased cancer incidence… would apply at the boundary of the uninhabitable area… At some locations [within that area] the dose rate would exceed this threshold by orders of magnitude." (**Thompson, pg 52 – emphasis added**)

#33 "35 million curies represent(s) the January 2003 inventory of fuel [Cs-137] in the Vermont Yankee pool…. 35 million curies would render about 80,000 square kilometers*(30,880 sq mi) uninhabitable…the combined area of Vermont, New Hampshire and Massachusetts is 70,000 square kilometers (27,000 sq mi)." (**Thompson, Pg 53**)

Conversion: *80,000 km^2 x .386 = 30,880 sq mi

R^2 = 30,880 ÷ 3.14159 [pi]

<u>Radius = 99 miles</u>

#34 The 300 tons of spent fuel Seabrook accumulated on-site by 2003 contains approximately 26 million curies of Cesium-137. If an attack on the Seabrook spent fuel pool caused the release of this material, it could render uninhabitable 23,000 square miles – or a radius of 86 miles.

Extrapolation for Seabrook – Cesium-137 inventory and affected area:

Seabrook's 300ton SF >> 26 million curies Cs-137

35 MCi / 30,880 sq mi***** = 26.25 / X

35X = 810,600 X = 23,160 sq mi

R^2 = 23,160 / 3.14159 [pi]

<u>Radius = 86 mi</u>

(*** Thompson, pg 53**)

#35 **“Robust” Protection for Spent Fuel”** What can concerned citizens do? First, we must demand that the atomic power industry return to a “low-\density open-frame” layout for their spent fuel pools.

#36 …This restores the safety component of ambient air cooling, which was originally part of the design basis for all reactors. “The simplest way to make room for open-frame storage at existing reactors is to transfer all spent fuel from wet to dry storage within five years of discharge from the reactor. Consequently, our proposal for open-frame storage is tied to proposals for dry storage…“ (**Alvarez et al, pg 19-21**)

#37 “Dry cask storage for older, cooler spent fuel, has two inherent advantages over pool storage: First, it is a passive system that relies on natural air circulation for cooling. Second, it divides the inventory of that spent fuel among a large number of discrete, robust containers. These factors make it more difficult to attack a large amount of spent fuel at one time, and also reduce the consequences of such attacks.” (**NAS – Finding 4D, pg 8**)

#38 “…shifting fuel to dry casks storage about 5 years after discharge from a reactor, would cost $3.5 -7 Billion for dry storage of the approx. 35,000 tons of older spent fuel that would, otherwise, be stored in US pools in 2010.” (**Alvarez, et al, pg 3**)[compare to monthly cost of Iraq War]

#39 “Dry-storage Independent Spent Fuel Storage Installations [or ISFSI’s] meet 1 of the 3 conditions for robust storage of spent fuel. They are passively safe, because their cooling depends on the natural circulation of ambient air. However, none of the existing or proposed ISFSIs is hardened, and none of them is dispersed across its site.” (**Thompson, pg 7 – italics added**)

#40 “A Spent Fuel Storage facility can be made resistant to attack in three ways: First, the facility can be made passively safe; Second, the facility can be ‘Hardened’; Third, the facility can be dispersed. …Most of [US Spent] fuel is stored at high density in water filled pools that are adjacent to, but outside, the containments of the reactors. This mode of storage does not meet any of the above-stated three conditions for robustness.” (**Thompson, pg 6)**

#41 -- The ISFSI must protect spent fuel against a range of possible attacks.
-- The cost should not be dramatically higher than the cost of an ISFSI built according to present practice.
-- The timeframe for building an ISFSI should be similar to the timeframe for building an ISFSI according to present practice.
-- The ISFSI should not, unless absolutely necessary, be built underground. (ref- **Thompson, pg 63 & 65**)

#42 “…thousands of tonnes of US spent fuel will remain in interim storage for decades, even if a repository opens at Yucca Mountain. If a repository does not open, the entire national inventory of spent fuel will remain in interim storage for many decades. Thus, the robust-storage strategy for spent fuel must minimize the overall risk of interim storage throughout a period that may extend for 100 years or longer.” (**Thompson, pg 57**)